Numerical evaluation of ASE, heat generation and energy extraction in a 100 J cryogenically cooled multi-slab amplifier operating at 10 Hz for HiLASE Project

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Outline

- Introduction
- Description of the model
- Results:
  - pump studies
  - population inversion
  - heat deposition
  - amplification
  - temporal evolution of ASE and the stored energy
  - spectral evolution of ASE
- Conclusion
- Plans for the future

Introduction

Stored energy and amplification are limited by ASE

Population inversion in the active medium:

$$\frac{dn}{dt} = \boxed{\left.\frac{dn}{dt}\right|_{P}} - \boxed{\left.\frac{dn}{dt}\right|_{SE}} - \boxed{\left.\frac{dn}{dt}\right|_{ASE}}$$

pump

spontaneous emission

amplified spontaneous emission

Energy of amplified photons changes with:

$$dJ = J(g_0 - \alpha)dl$$

Bulk parasitic oscillations condition: $R\exp[n_2/n_1(\alpha D)]=1$

The model:

Pump rays

↓

Population inversion

↓

Spontaneous emission

↓

Ray-traceing + amplification

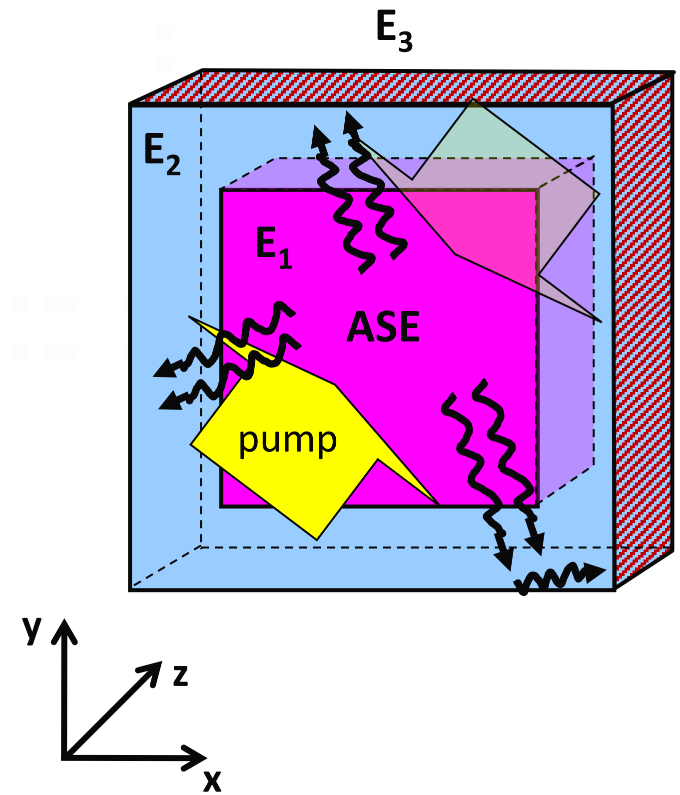
↓

Absorption & Scattering

↓

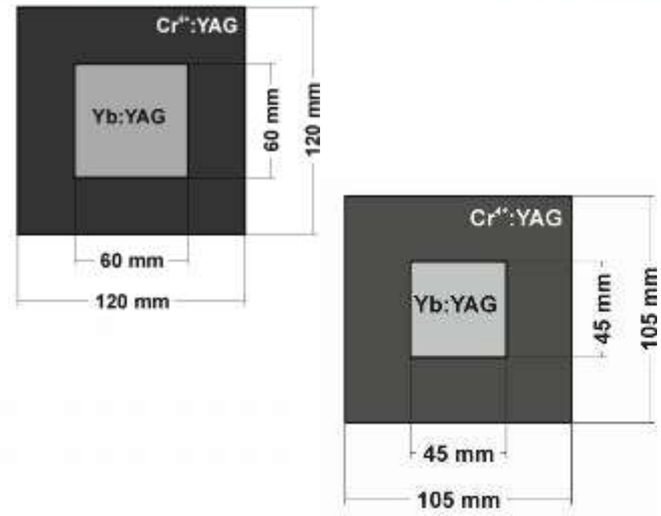
Change of population inversion

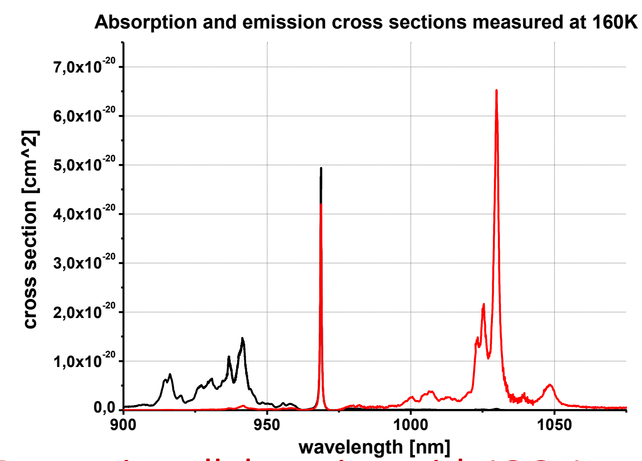
→ (back to Pump rays)



Amplifier parameters

- Yb:YAG gain medium @ 160K
- 8 slabs
- 60x60x8 mm^3 or 45x45x7 mm^3 or 45x45x8 mm^3 with 4 mm gap
- Variable or constant Yb ions concentration designs
- 30 mm of Cr:YAG absorptive layer*
- Cr^{4+} concentration: 0.34 at. %
- Wavelength resolved cross-sections



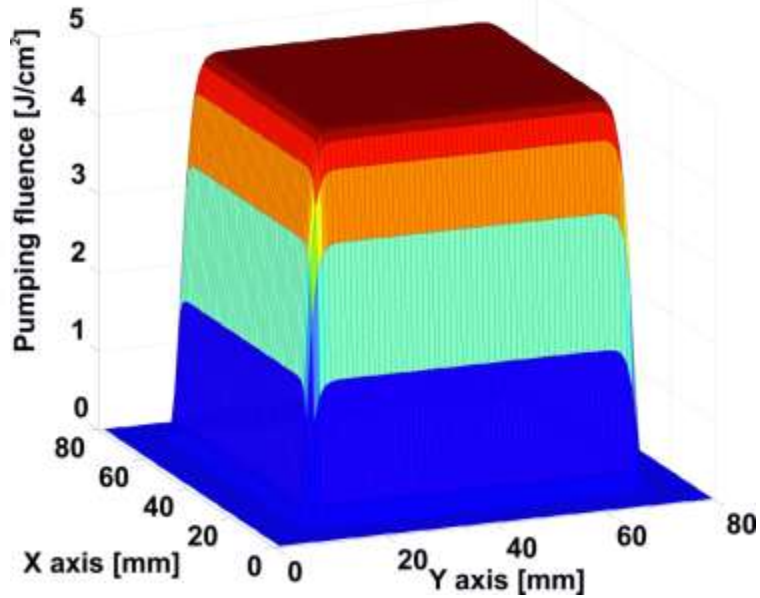


* proposed and tested by DiPOLE CLF RAL UK

IoP-Prague in collaboration with IOQ-Jena

Pump parameters

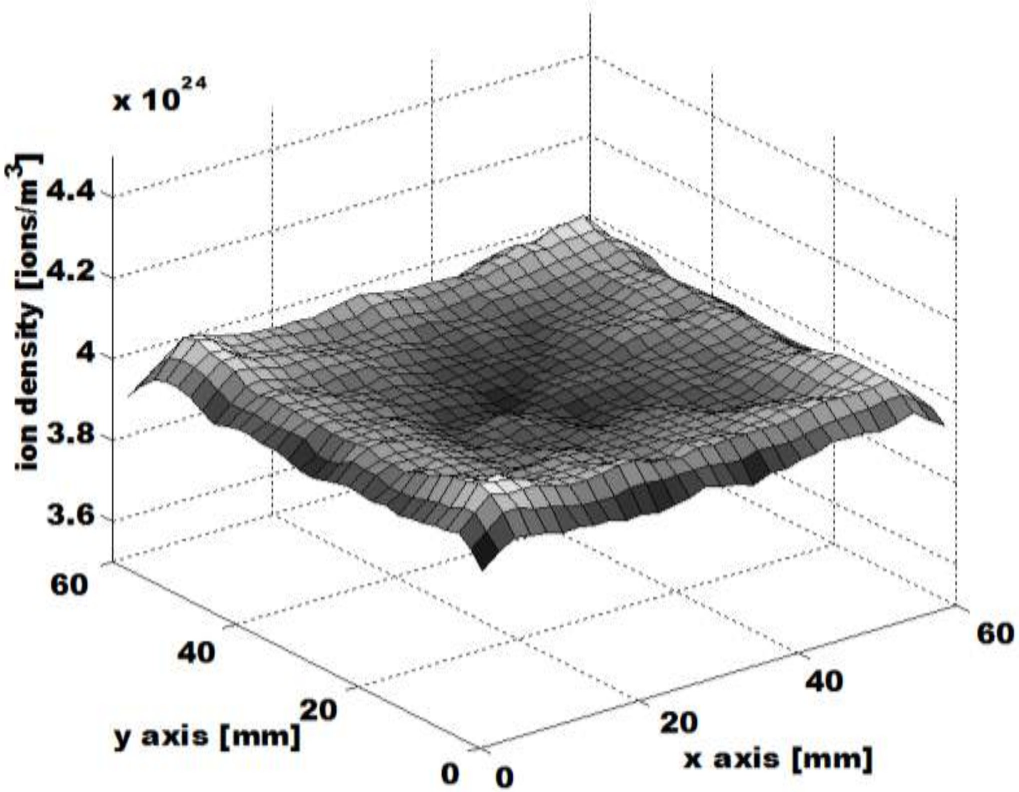
- Pumped from both sides
- Polychromatic pump
- Central wavelength: 938 nm
- FWHM 6 nm
- Pump fluence: 2x5 J/cm2
- Pump energy: 360 J or 202.5 J
- Super-gaussian (16th order) beam profile
- Pump duration: 1 ms



Pump parameters

		wavelength [nm]						
		935	**936**	**937**	**938**	**939**	**940**	**941**
bandwidth FWHM [nm]	**3**	0.526	0.532	0.535	0.533	0.535	0.535	0.533
	4	0.526	0.530	0.533	0.535	0.535	0.535	0.533
	5	0.526	0.529	0.532	0.535	0.535	0.533	0.530
	6	0.526	0.529	0.532	**0.533**	0.533	0.532	0.526
	7	0.526	0.529	0.530	0.532	0.532	0.527	0.522

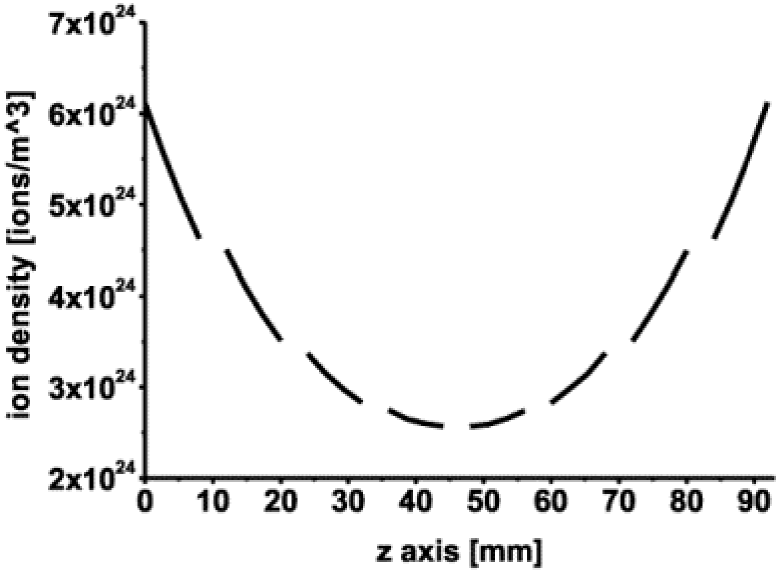
Transverse map of population inversion

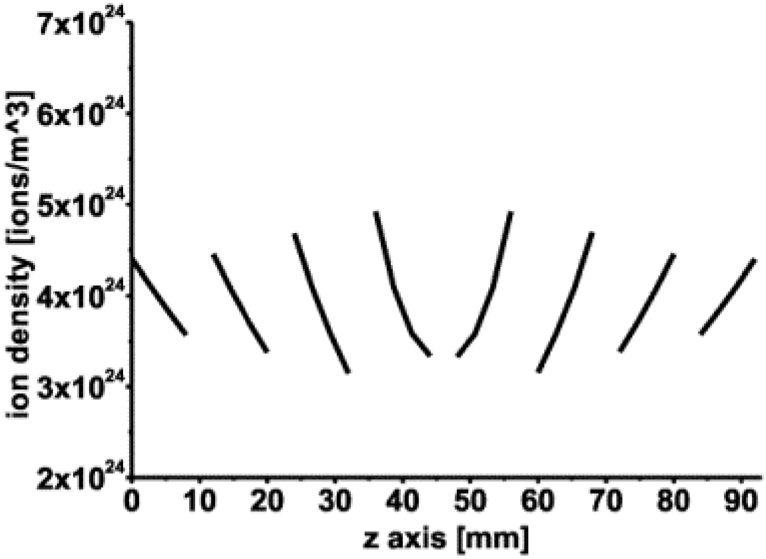


Parameters used for the simulation:

- 8 slabs 60x60x8 mm^3 each
- variable doping concentration
- pumped from both sides
- 16th order super-gaussian pump beam profile
- pumping fluence: 2x5 J/cm2

Influence of the doping concentration



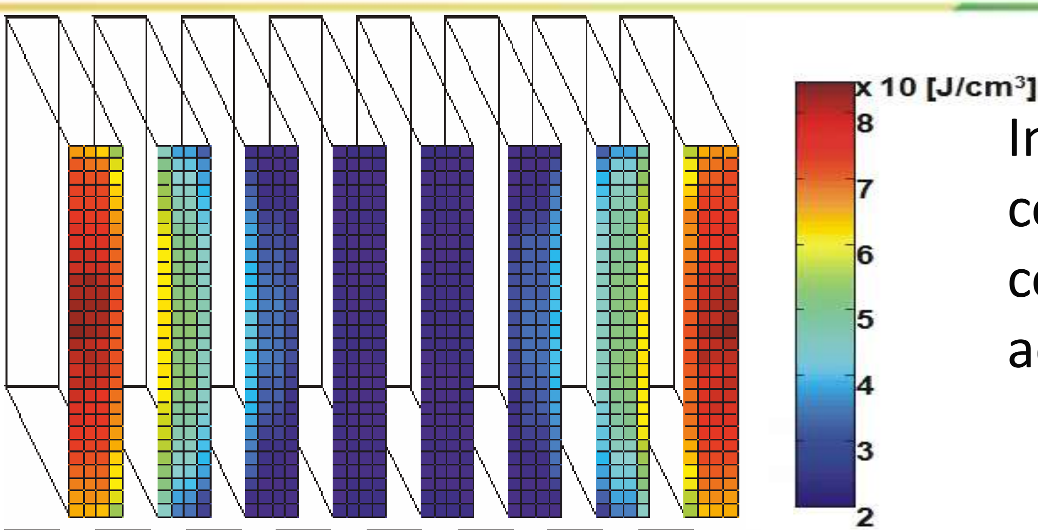


8 slabs 60x60x8mm^3 each
Constant doping:
0.5 at. % in all slabs

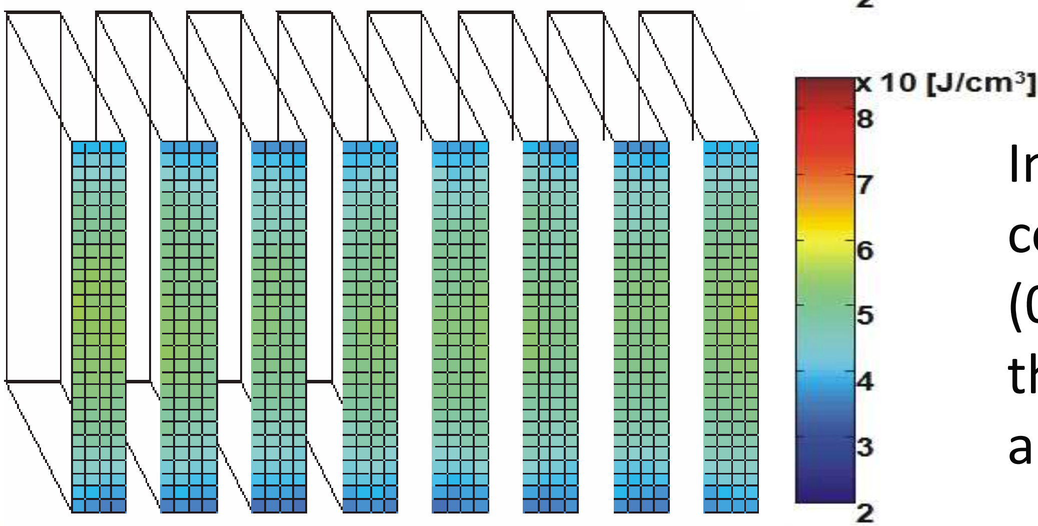
8 slabs 60x60x8mm^3 each
Variable doping along slabs :
0.3- 1.3 at. %

Sawicka et al., JOSA B, Vol. 29, Issue 6, pp. 1270-1276 (2012)

Longitudinal heat deposition



In the first case the doping concentration of each slab was constant (0.5 at. %)- heat accumulates in the outer slabs



In the second case the doping concentration varies along slabs (0.3 at.%-1.3 at.%) which results in the homogeneous heat deposition along slabs

Different treatments of the side walls

Aperture size	60 mm x 60 mm		
thickness of the slab [mm]	8	8	8
Pumping	both sides	both sides	both sides
total pump fluence[J/cm^2]	10	10	10
total pump energy [J]	360	360	360
Reflectivity of the side walls	**R=50%**	**R=30%**	**R=0**
Eunabs [J]	5,7	5,8	5,8
Estored [J]	101,8	144,7	190,8
Eabs in walls[J]	225,3	178,0	133,6
Eout [J]	13,3	16,5	17,4
A=Ease/Ese	**1,87**	**0,84**	**0,26**
η_{st}	0,28	0,40	0,53

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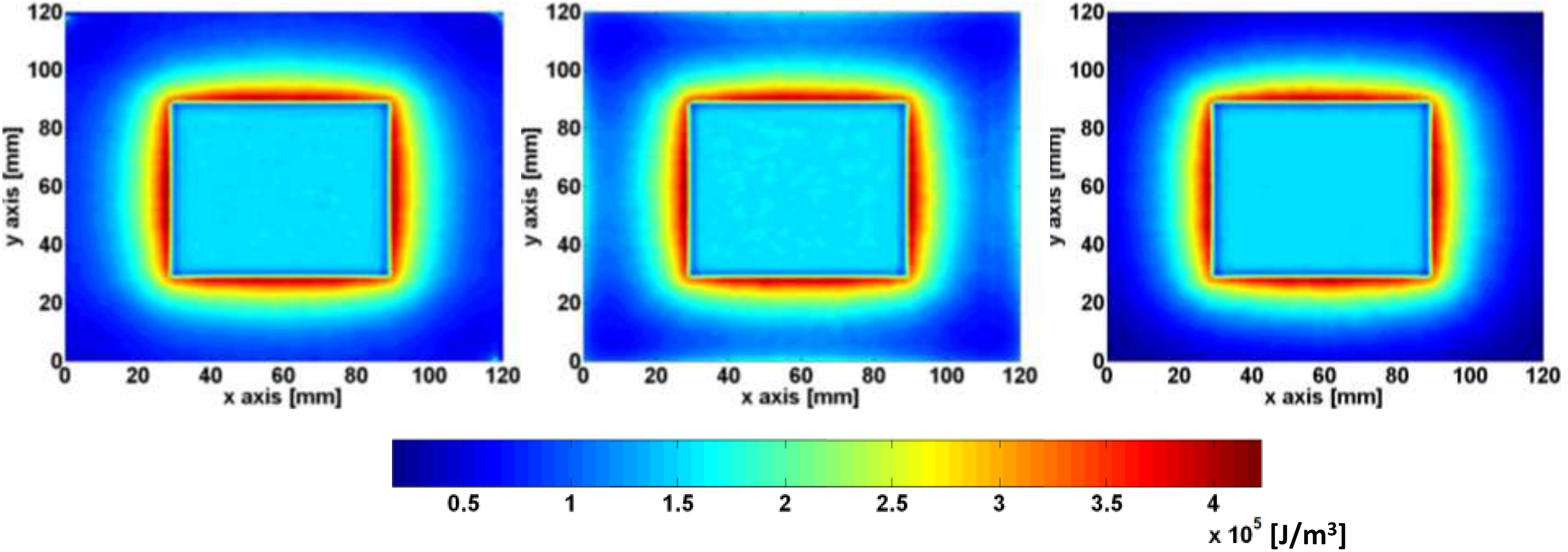
What can happen at the edge of Cr:YAG

With Fresnel losses | **With scattering** | **100 % absorption**

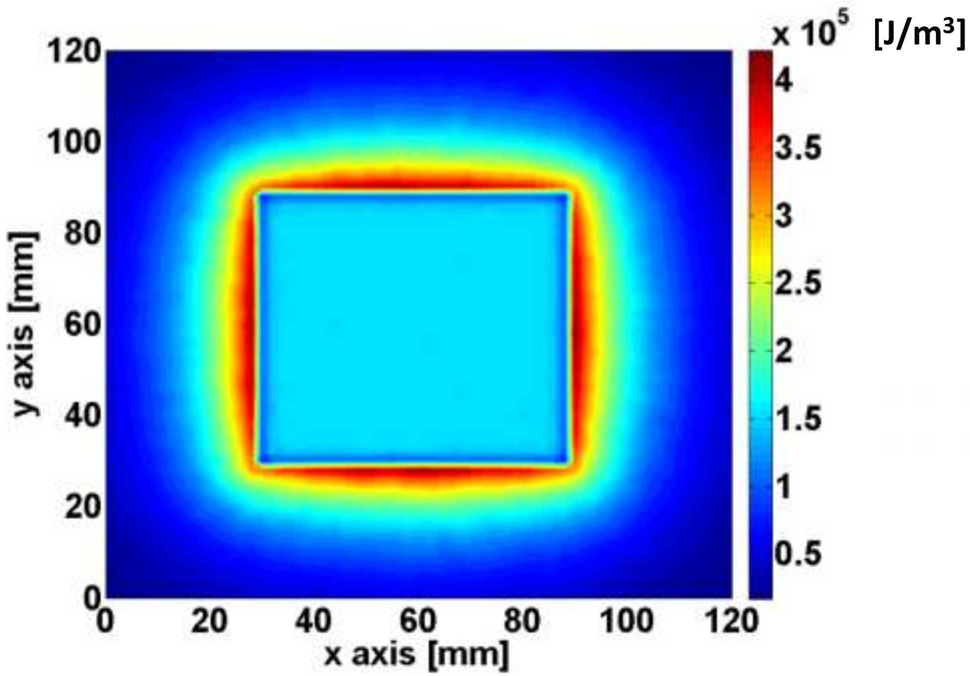


η_{st}=0.52
A=0.28

η_{st}=0.53
A=0.27

η_{st}=0.53
A=0.26

Transverse heat deposition



50 % of pump energy is stored in the gain medium

10 % is absorbed in Yb:YAG due to defects and converted into heat

30 % is absorbed in the cladding and converted into heat

10 % escapes from the active medium

Energy balance done for:

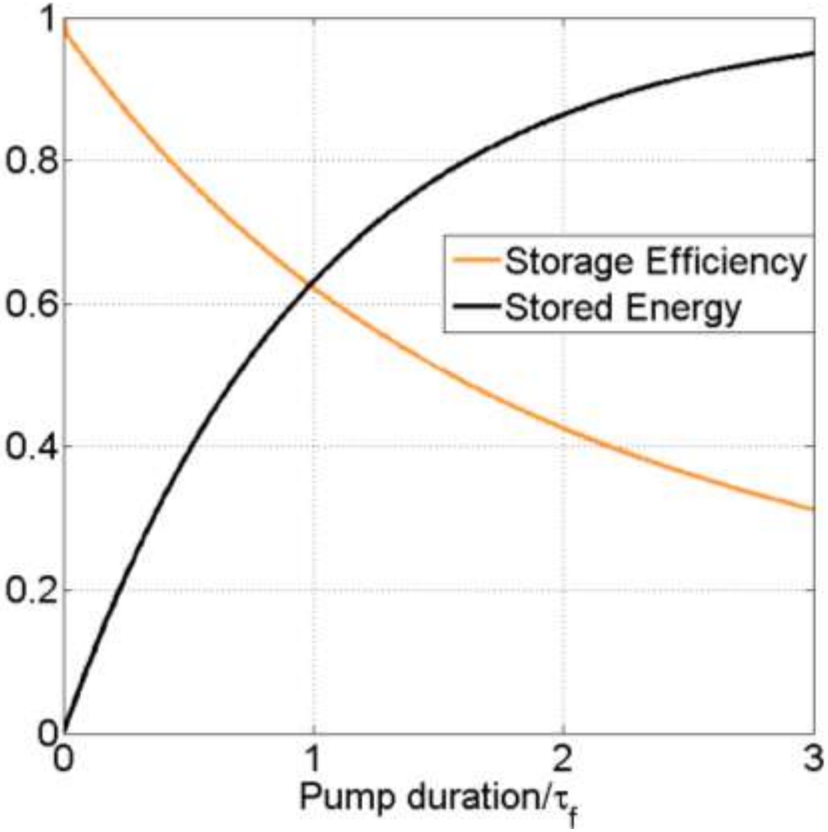
- 8 slabs 60x60x8 mm^3 each
- with 30 mm of Cr:YAG layer with 0.34 at. % concentration
- variable doping concentration of Yb ions
- 360 J of pump energy
- R=0 at side walls

Energy balance

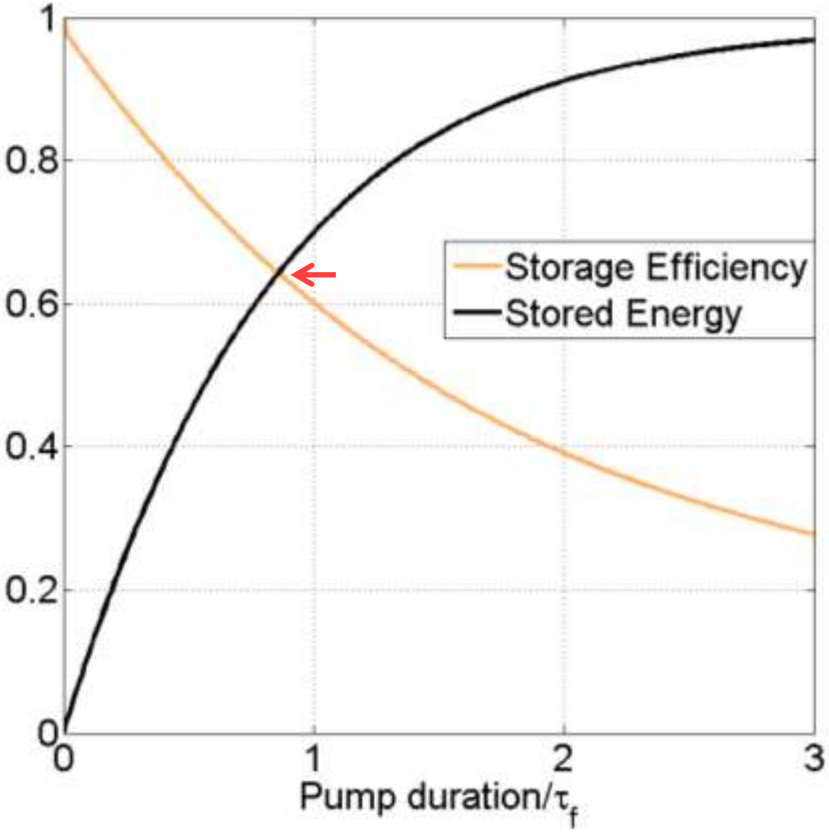
Aperture size	45 mm x 45 mm		60 mm x 60 mm
thickness of the slab [mm]	7	8	8
Yb doping concent.	0.4 0.55 0.86 1.5 1.5 0.86 0.55 0.4	0.34 0.46 0.72 1.34 1.34 0.72 0.46 0.34	0.34 0.46 0.72 1.34 1.34 0.72 0.46 0.34
Pumping	both sides	both sides	both sides
CrYAG thickness [mm]	30	30	30
Cr doping conc.	0.34	0.34	0.34
total pump fluence[J/cm^2]	10	10	10
total pump energy [J]	202,5	202,5	360
Eunabs [J]	3,2	3,3	5,8
Estored [J]	**109,5**	**111,0**	**190,8**
Eabs in walls[J]	73,5	72,5	133,6
Eesc [J]	9,3	8,8	17,4
A=Ease/Ese	**0,22**	**0,19**	**0,26**

Temporal evolution of Est

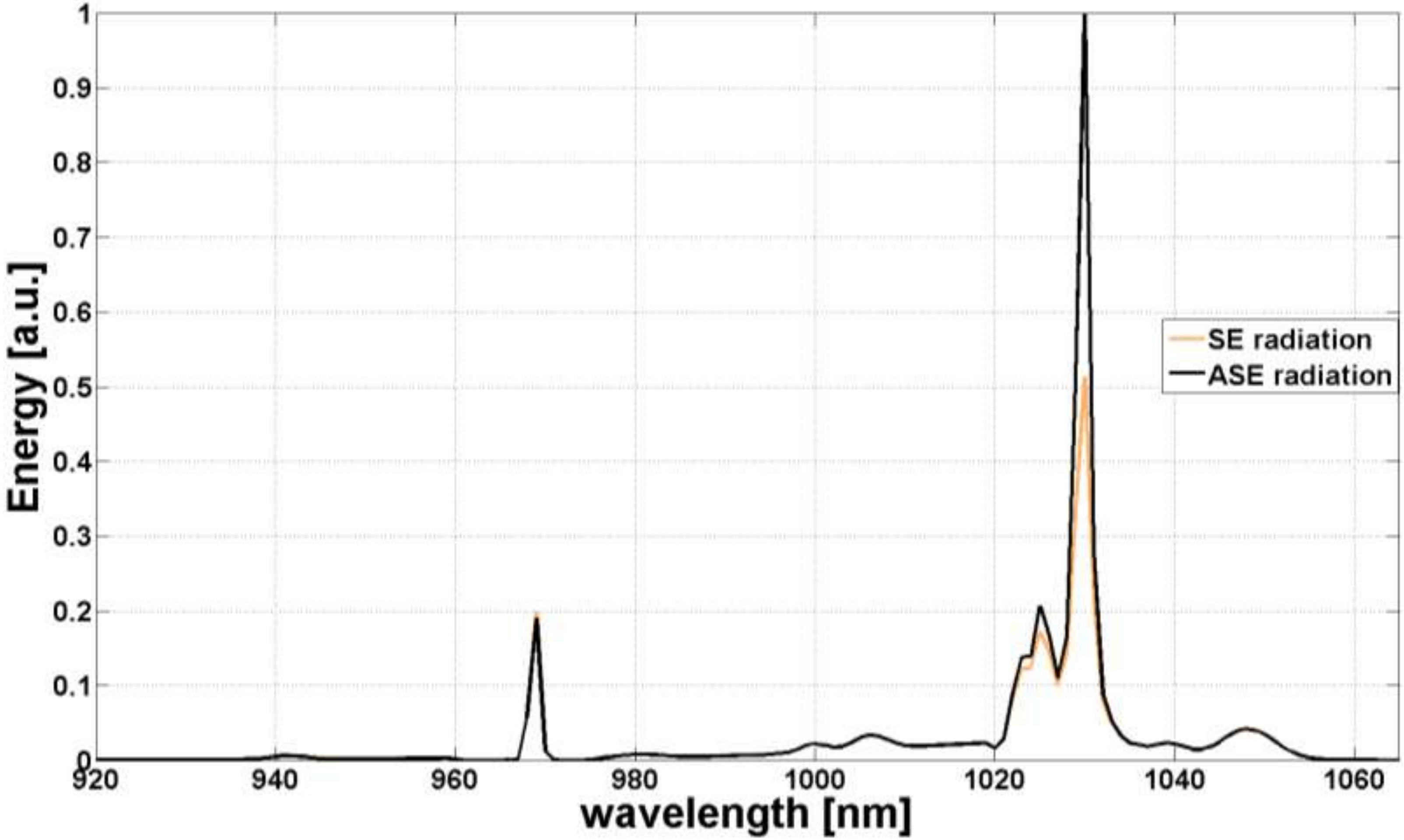
Without ASE



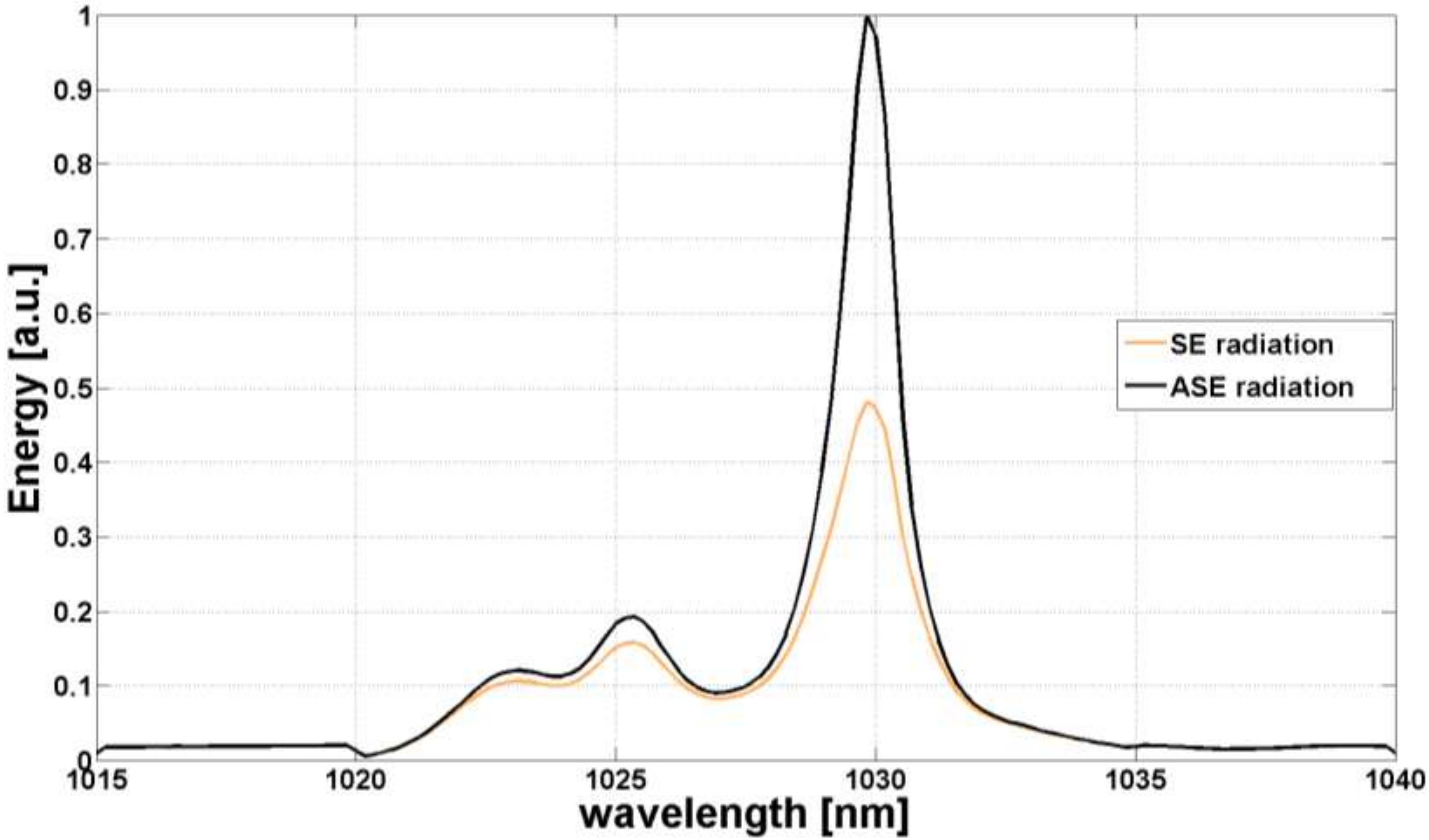
With ASE



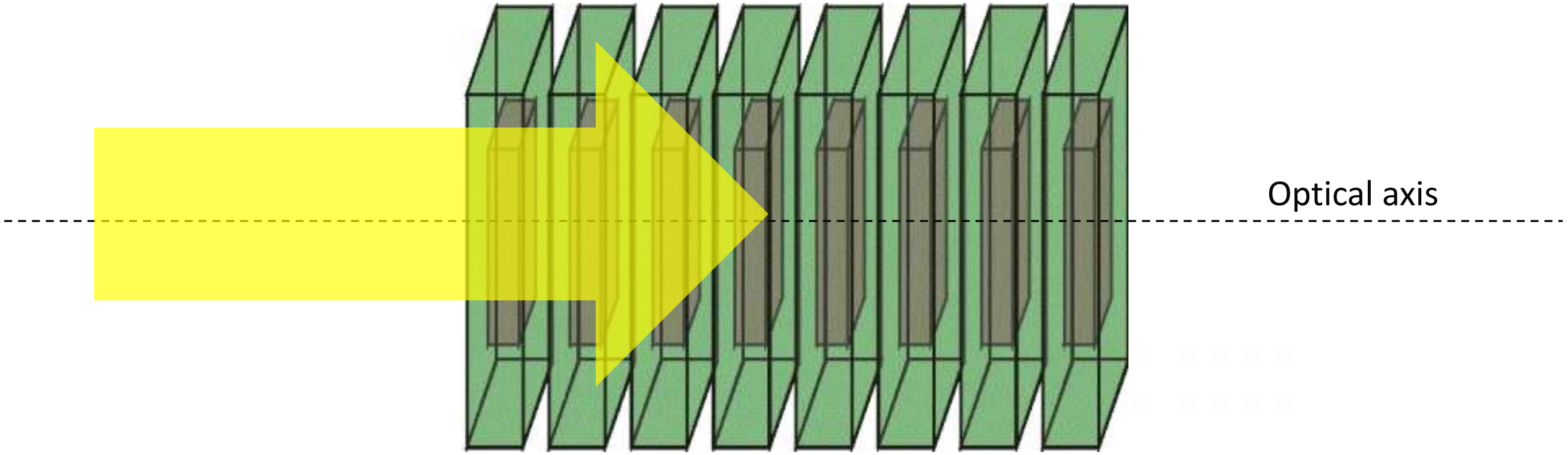
Spectral evolution of ASE radiation



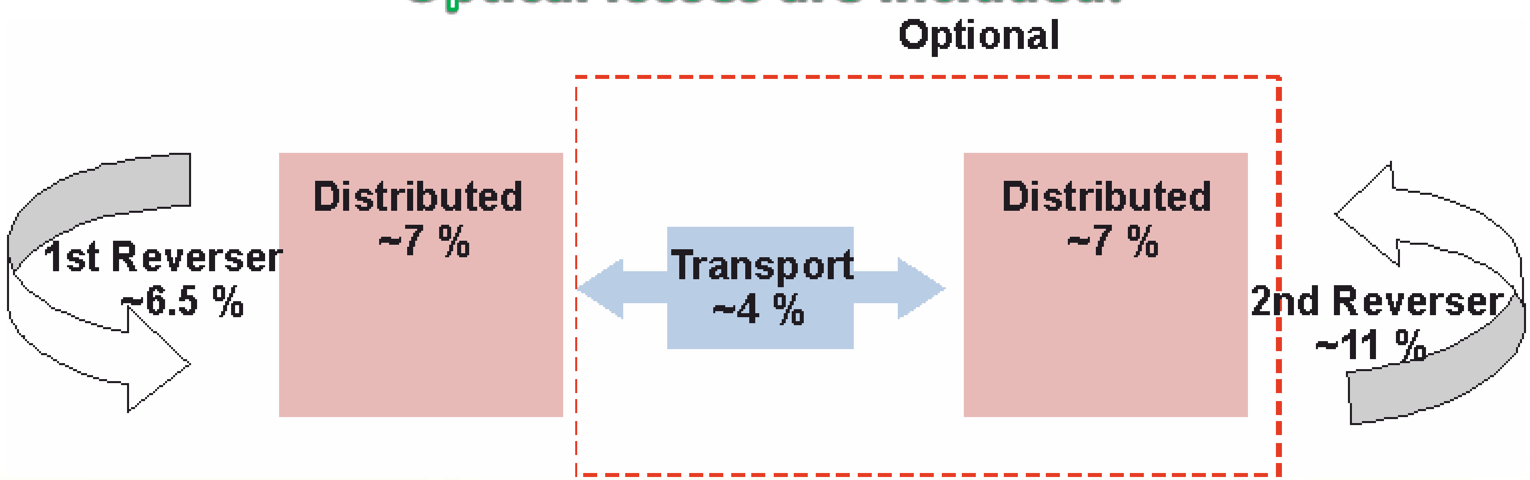
Spectral evolution of ASE radiation



Amplification process



Optical losses are included:



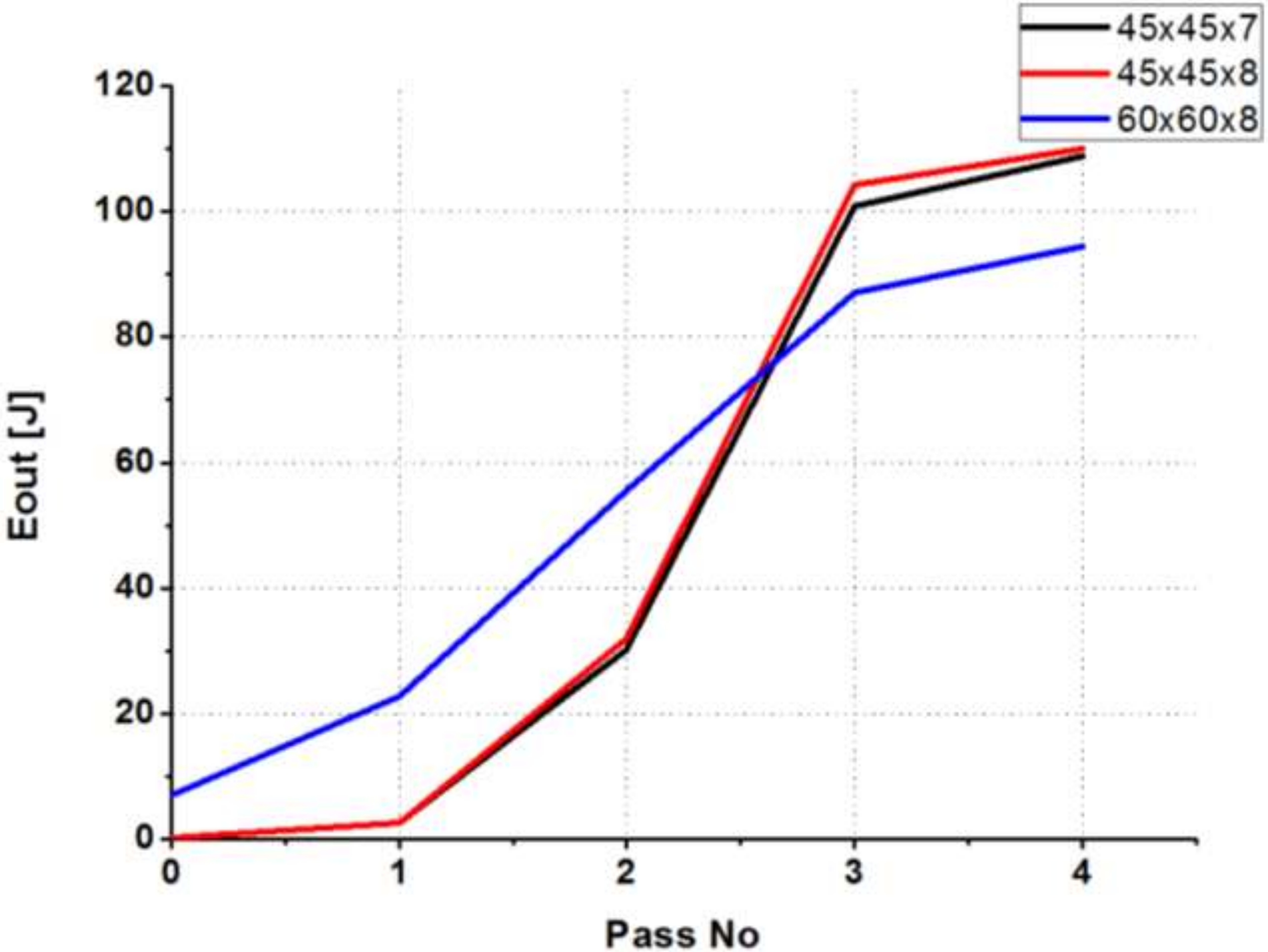
Results of the amplification

Amplification done for:

- 10 J/cm² of pump fluence
- 8 slabs 60x60x8 mm³ each with 30mm of Cr:YAG layer
- Seed energy fluence: 0.2 J/cm²

- 16 slabs 45x45x8 mm³ each with 30mm of Cr:YAG layer 2 heads
- Seed energy fluence: 0.008 J/cm²

- 16 slabs 45x45x7 mm³ each with 30mm of Cr:YAG layer 2 heads
- Seed energy fluence: 0.008 J/cm²



Optical losses included

Conclusions

- 3D model of multislab amplifier for energy storage, heat distribution and amplification has been presented
- Heat deposition -> Comsol
- Stored energy (gain) -> Miro
- Different slab walls treatmeants were investigated
- 3 different amplifier head architectures have been designed and compared
- In each design, the seed beam can be amplified up to 100 J

„To do" list

- Measurements of spectroscopic parameters of the active material at cryogenic temperatures with the resolution of 20 pm.
- Measurements of scattering on roughened surfaces
- Experimental benchmarking of the program